REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
29-March-2007	Final Report	01/Jan/2003 - 31/Dec/2006

4. TITLE AND SUBTITLE
Semantic Source Coding for Flexible Lossy Image Compression

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-03-1-0231

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER
Final Report

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10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; distribution is Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Office of Naval Research position, policy or decision, unless so designated by other documentation

14. ABSTRACT
Semantic Source Coding for Lossy Video Compression investigates methods for Mission-oriented lossy image compression, by developing methods to use different compression levels for different portions of an image based on their utility in understanding the scene depicted. We have used semantic methods, including pattern discovery, wavelet-based segmentation and texture segmentation to extract the essential predictive information in the image. Described are mission oriented approaches to image pre-processing, image and video segmentation, quality comparison, compression, and two complete systems for lossy video compression

15. SUBJECT TERMS
Pattern Discovery, Semantic Methods, Lossy Video Compression, Lossy Image Compression, Image Segmentation, Texture Segmentation, Multi-Resolution Wavelet

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Shashi Phoha
unclassified	unclassified	unclassified		34	19b. TELEPHONE NUMBER *(Include area code)* 814-863-8005

Grant Information

Grant Number	N00014-03-1-0231
Title of Research	Semantic Source Code for Flexible Lossy Image Compression
Principal Investigator	Dr. Shashi Phoha
Organization	Penn State – ARL

Technical Section

Objective

This research addresses the severe power constraints and bandwidth limitations in the observation of the battlefield by war fighters using video data. New dimensions of network centric electronic warfare, such as the Expeditionary Sensor Grid will further stress these constraints. We develop an algorithm for the real-time processing of mobile video sensor data by devising knowledge-based methods for efficient compression and coding. Advances in data compression are needed to address this challenge. Bandwidth must be rationed so operationally important information is transmitted with higher resolution than extraneous details.

Approach

We formulate mathematical techniques for local processing of raw sensor data into semantic information with flexible resolution, related to battlefield objects and their behaviors. Three increasing sequential levels of compression and coding are developed. They are being tested in laboratory experiments using mobile robots and implemented in a prototype system.

The first level of compression involves a functional decomposition of video data into *spatio-temporal wavelets*, facilitating the semantic interpretation introduced at the next level. The second level of compression groups the wavelets into sets corresponding to moving objects and background then transforms each set of numerical data into a formal language and transmits only the *formal grammars*. The third level of compression creates a codebook of formal grammars corresponding to generic scene components. Formal languages created from sensor data will be matched against codebook languages using a *formal language measure*. If a match is found, only the codebook index need be transmitted.

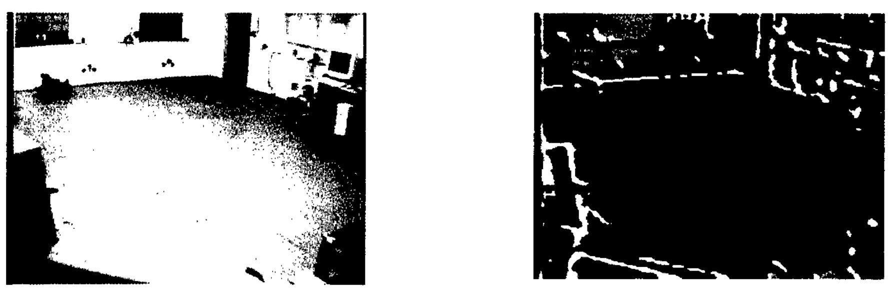
Progress

1. Video Processing Testbed

We have further developed a video processing testbed for the development and testing of our video compression approaches. This testbed includes implementations of all algorithms and software mentioned below.

2. Texture Segmentation Using ε-Machines

We have developed an algorithm for ε-machine based texture segmentation, which is more efficient than the current state of the art using graph-based methods. This segmentation algorithm combined with the development of Dynamic Window CCSA (see below) allows for real-time segmentation of video textures, a key element in the construction of our code book testbed. In addition, to improve texture segmentation results we developed and tested a method for wavelet encoding. This encoding extracts relevant dynamics around pixels and provides these as easily symbolized input to the texture segmentation algorithm.



Original Image

Texture Segmentation

Figure 1. Texture Segmentation Results on Robot Image

3. ε-Machine Software

Two years ago we designed the Clustered Causal State Algorithm (CCSA), which produces causal state machines with nearly the accuracy of the Causal-State Splitting Reconstruction (CSSR) the current state of the art, while operating ten to a hundred times faster. Last year we followed this up by developing two additional refinements of CCSA.

First, we implemented a version of CCSA incorporating the k-means approach to clustering, enabling us to generated machines rapidly, but with a fixed number of states. The accuracy of this algorithm is comparable with the conventional CCSA.

Second, we implemented Dynamic-Window CCSA and algorithm designed to fulfill the need of texture segmentation (see below), which requires rapid generation of machines for many consecutive windows of the symbol stream, by use of a sliding window of information. Combined

with statistical metrics DW-CCSA automatically group patterns together in a symbol stream, enabling hierarchical analysis and uncalibrated phase-change detection.

4. Mission-Oriented Image Metrics

We have investigated the development of mission oriented image metrics to better compare the utility of images and video for use in the field. We have developed two metrics, both using a graph-based region segmentation algorithm, one weighing pixel-by-pixel comparison towards region boundaries, and the other weighing all regions equally to ensure that the retention of smaller foreground elements was not outweighed by larger background features.

5. Code Book Testbed

One of the culminating goals of this project is the development of a code book testbed to demonstrate the capabilities of converting image portions into code book elements in reducing bandwidth costs. The basis of this testbed has been designed, including use of sockets to ensure realistic bandwidth measurement and incorporating techniques for the transmission compression of machines, image fragments, and segment boundaries. The receiving side of this testbed incorporates existing texture reconstruction technology to be run in real-time, recreating images based on code book entries, which are determined by texture segmentation performed by DW-CCSA.

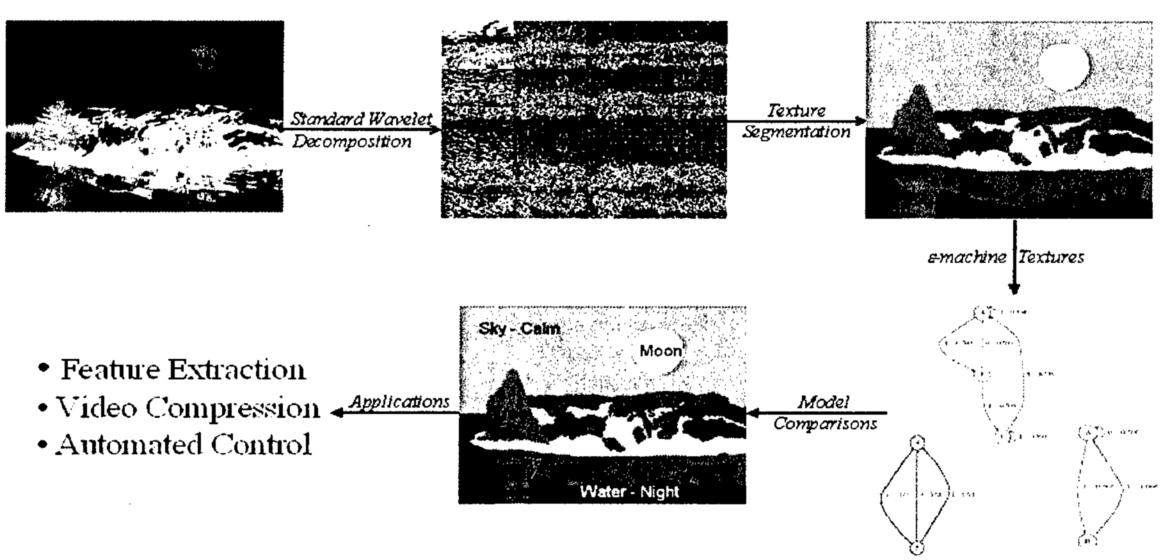


Figure 2 – Code Book System Diagram

6. Conclusions

We have assembled and vetted the components of a semantic video image compression and code booking system. Preliminary integration has shown the compatibility of the component technologies and suggests future applications for both the system and its components.

Cumulative Statistics

Publications

M. Schmiedekamp, A. Subbu, and S. Phoha, The Clustered Causal State Algorithm: Efficient Pattern Discovery for Lossy Data Compression Applications. *Computing in Science and Engineering*. Vol. 8, Num. 5, p 59-67, Sept 2006

Omatick, B, *A New Lossy High Compression Algorithm for Video*, Baccalaureate Honors Thesis in Computer Science, August 2004, Pennsylvania State University.

A. Subbu, "Lossy Image Compression: A Clustering Based Approach," Master Thesis in Electrical Engineering, April 2005, Pennsylvania State University.

Conference presentations/proceedings .

S. Phoha, D. Friedlander, M. Schmiedekamp, A. Subbu, D. Boykis, S. Patel, "Semantic Sourecoding for Lossy Video Compression," First Annual Computation Day, Pennsylvania State University, Feb. 17th, 2005, Poster Presentation.

Invention disclosures/patents

Texture Segmentation from On-line Pattern Discovery (in progress)

Awards or other noteworthy recognition

2004 IEEE Computer Society Technical Achievement Award, Nov. 2005

Students/Postdocs supported by this grant

This project supported three undergraduate students and one graduate student. Ms. Brianne Omatick has worked on the project from June 2003 to August 2004 as an undergraduate research assistant and has completed her honors thesis based on this research, *A New Lossy High Compression Algorithm for Video*. A graduate student, Aparna Subbu has been working on the project since August 2003. She completed her masters thesis based on research performed on this project. Her doctoral dissertation will be related to the topic as well. Lastly, two additional undergraduate research assistants joined the project in September 2004, Dan Boykis and Shivang Patel. Dan Boykis replaced Brianne and worked on the project until August 2006. Shivang Patel was also funded by internal research funds and worked on the project until May 2006.